MILL CREEK OHIO DEEP TUNNEL PLAN

RICHARD L. PRUITT

HYDRAULIC ENGINEER
LOUISVILLE DISTRICT COE
600 DR. MARTIN LUTHER KING JR. PLACE,
LOUISVILLE, KENTUCKY 40202-2230
502-582-6460
Richard.L.Pruitt@LRL02.usace.army.mil

ABSTRACT

A General Reevaluation Report is now being conducted by the Louisville District to study methods of flood control for this stream within Hamilton County, Ohio. One of the methods of flood control that is supported by local interests is a deep tunnel plan, with the tunnel set about 300 feet below existing ground for a length of 16 miles. Five intake structures are located in the upper portion of Hamilton County to remove excess flows into the tunnel and provide minimal damages for the 1% chance (100-year) flood. Runoff from Mill Creek would enter the tunnel beginning at a 50% chance (2-year) flood to help reduce the more rare events.

Another benefit of a tunnel would be the removal of Combined Sewer Overflows (CSO) at 74 locations along Mill Creek. At present it is estimated that 2.867 billion gallons per year of CSO is discharged into Mill Creek. These CSO's would enter the tunnel for events more frequent than a 50% chance flood to be stored for treatment at the waste water treatment plant (WWTP). In order to reduce the cost of this alternative, the 74 locations of CSO discharge are consolidated by collector sewers such that only 20 drop shafts would be required for CSO discharge.

GENERAL

Mill Creek lies in southwest Ohio, a majority of which is located in Cincinnati and Hamilton County, Ohio. Under present day conditions, there are over $32 million dollars of average annual damages with $480 million dollars damage for the 1% chance flood. The Mill Creek basin is generally bounded by the Miami River basin to the northwest, the Little Miami River basin to the east, and the Ohio River to the south. The total fall of Mill Creek from its headwaters, located in Butler County, to the barrier dam near the mouth is about 350 feet in elevation. In the upper portion of this watershed, located in Butler County, the valley bottom is wide, averaging 1-1/2 miles, but it narrows in the downstream reaches located in Hamilton County, averaging only ½ mile through the City of Cincinnati. In the lower portion of the basin, valley walls are steep, rising 200 to 300 feet above the valley floor. The lower portion of Mill Creek is urban in nature and is almost totally developed. This development consists of a mixture of industrial, commercial, residential, transportation, and public properties. Industries within the Mill Creek flood plain include Ford Motor Company, General Electric, General Mills, as well as other smaller industries. The upper portion of the watershed in Butler County is more rural. However, industrial development within the flood plain is starting to occur.

HISTORIC STORMS & FLOODS

The January 19-21, 1959 flood, the most severe storm when backwater of the Ohio River did not occur, was caused by precipitation typical of great winter storms in the Ohio River basin when southerly winds transported a large mass of warm moist air from the Gulf of Mexico to the Ohio valley. This system contacted a high-pressure system from the south Atlantic coast and a low-pressure system over the Great Plains causing the axis of the storm to occur along the Ohio River from its mouth to Cincinnati. Rainfall of up to 6 inches was recorded with runoff being high due to antecedent rainfall that occurred on January 14th through the 17th as well as the freezing weather conditions. This storm was approximately equal to a 4% chance (25-year) flood.

An April 16, 1998 flood was one of the most recent typical summer type floods. Rainfall depths varied throughout the upper half of the Mill Creek basin, where flood damages occurred, from about 2.0 inches at the Butler County Sewage Treatment Plant to about 4.2 inches at Sharonville, Ohio. This 18-hour storm corresponded to between a 10% chance (10-year) and 4% chance (25-year) flood. Lastly, in July 2001 widely scattered heavy rainfall in Southwest Ohio, including the Mill Creek basin, caused flooding in this same damage area as the 1998 flood. Flooding for this site was slightly greater than in April 1998 with a frequency approaching 4% chance (25-year). In surrounding drainage basins this rainfall approached 4 to 8 inches of rainfall in about a one hour duration. However, for the Mill Creek basin rainfall totals and intensities did not approach this level.

EXISTING FLOOD CONTROL MEASURES

In order to provide protection against Ohio River backwater flooding, a barrier dam with pumps was constructed starting in January 1941 and completed in March 1948. As part of the Mill Creek Local Protection Project, two additional pumps were added to the Mill Creek plant in 1991 with total capacities ranging from about 12,400 cfs to 14,400 cfs.

To provide protection against Mill Creek headwater flooding in Hamilton County, channel improvements were constructed along various sections of Mill Creek. This improved channel was designed to provide a 1% chance (100-year) level of protection as referred to at the time of the original study from the barrier dam upstream to near the Hamilton Butler County line at Mile 18.2. Construction of the improved channel began in 1981 but was suspended in 1991 at the direction of the Secretary of Army (Civil Works) due to inflated project costs, the presence of hazardous materials and contaminations, questions concerning the ability of the local sponsor to pay their share of the project, as well as other complications. The portion of the completed channel modification began at the barrier dam near the mouth of Mill Creek and continued upstream to about Mile 10.0. The Louisville District is in the process of performing a General Reevaluation Report (GRR) to study flood protection measures, including the deep tunnel plan, for the uncompleted portions of Mill Creek from Mile 10.0 upstream to the County line at Mile 18.2.

PRINCIPLE FLOOD PROBLEMS

Flooding has been a chronic problem on Mill Creek for some time with the March 1913 event, the flood of record. However, the most damaging flood occurred in January 1959. There have been numerous other headwater floods of lesser magnitudes such as those that occurred in May 1996, April 1998, and July 2001. A detailed economic analysis showed that for existing conditions, significant damages would occur from a flood with a 50% chance (2-year) of occurrence. For the 1.0% chance (100-year) flood, there are approximately 560 structures located in the flood plain with total residual damages of over $480 million with the existing COE flood control project in place. Total average annual damages for the study area under existing conditions are over $32 million with about 92% occurring above Glendale Milford Road in the Evendale and Sharonville areas. Table 1 shows a tabulation of total damages and number of structures flooded for a range of frequency floods. Damages shown on the table below are assumed to begin when floodwaters initially come in contact with the structures within the flood plain. These damages are based upon an economic analysis update for Mill Creek dated June1997.

TABLE 1

EXISTING CONDITION FLOOD DAMAGES

NUMBER OF STRUCTURES FLOODED

Frequency Flood	Structures Flood	Flood Damages ($000)
100% (1-Year)	6	141
50% (2-Year)	18	703
20% (5-Year)	83	25,481
10% (10-Year)	204	103,564
5% (20-Year)	333	202,823
2% (50-Yeae)	478	323,463
1% (100-Year)	557	486,417
.2% (500-Year)	897	910,196

MILL CREEK DEEP TUNNEL PLAN

During this GRR, many methods of flood control have been and are continuing to be studied, including deep tunnel plans. One proposed tunnel alternative would have the upstream end of the tunnel beginning near Mile 18.2 at the Hamilton County Butler County line and continue downstream to the barrier dam near the mouth of Mill Creek. Another tunnel plan now being studied would also have the tunnel begin near Mile 18.2 but would continue downstream only to Mile 10.0 where the existing Corps of Engineer channel modification begins as mentioned in the above section "Existing Flood Control Measures". For both alternatives, the tunnel profile depth would be set about 300 feet below the existing ground surface.

The locally preferred plan for this GRR is the deep tunnel plan beginning at Mile 18.2 continuing to the barrier dam near the Ohio River. The plan producing the maximum net benefits, the NED plan, at this time is the shorter length tunnel plan that ends at Mile 10.0. The objective of these plans are to reduce the risk of flooding for the 1% chance (100-year) flood along Mill Creek by diverting excess flows into the tunnel at five intake structures located in the mid to upper portion of the basin. For the locally preferred plan, an additional objective is to divert combined sewer overflows (CSO's) into the tunnel in lieu of the creek itself. A majority of these CSO's are located in the lower reaches of Mill Creek in the older more heavily developed areas of Cincinnati.

TUNNEL PROFILE LAYOUT

The options for the tunnel are basically limited to three layouts. These include soft ground, shallow rock, and deep rock tunnel profiles. The soft ground tunnel profile runs through the soil strata consisting of sands and gravel interbedded with lacustrine clays and glacial tills. The shallow rock profile maintains approximately 50-feet of cover over the crown of the tunnel for optimum roof stability. This shallow rock alignment lies partially in the Point Pleasant formation, consisting of interbedded shale with limestone and partially in the underlying Lexington Limestone formation, consisting of interbedded limestone with shale. The deep alignment profile sets the tunnel at a depth were it is partially in the Lexington Limestone formation and partially in the underlying Black River Group, consisting of massive dolomitic limestone with occasional bentonite beds. As long as there are at least two diameters of cover over the tunnel crown, whether in rock or soil, the tunnel profile could be set at any reasonable depth from a tunneling perspective.

Probably the most heavily weighted parameter considered in setting the tunnel profile is the estimated construction cost of the completed facility along with its final operating and maintenance costs. In regards to the tunnel costs, the general rule for tunnels is that soft ground tunnels are more expensive than rock tunnels. In addition, from a geotechnical ground behavior perspective, tunnels in soil tend to have a greater chance of ground movements influencing surface structures and utilities.

When evaluating the rock alignments for Mill Creek, several factors about the rock formations were characterized. The Point Pleasant and Lexington Limestone formations will require modest amounts of rock bolting and mesh for post excavation support, after which the final lining can be installed by cast-in-place or pre-cast methods. The Black River formation, while being more massive and higher strength resulting in more stand up time and less crown support, contains several bentonite layers ranging in thickness from 6-inches to 2-feet. This highly expansive and weak bentonite layers cause potential squeezing ground conditions and also create extremely weak failure planes along the layers, whether in the excavation or a tunnel diameter above or below the excavation. In addition, the lower portions of the Lexington Limestone as well as the Black River Group contain several occurrences of natural gas, including methane and hydrogen sulfide. The decision on which tunnel option to use will not be decided upon until late this summer. However, at this time, the occurrence of the bentonite and natural gases, make this deep rock tunnel plan less attractive.

MILL CREEK FLOOD CONTROL

As stated earlier, the objective of these deep tunnel plans are to reduce the risk of flooding for the 1% chance flood along Mill Creek by diverting excess flows into the tunnel. Because of the existing channel modification from the barrier dam to Mile 10.0 that provides 1% chance level of protection as described in the previous Section "Existing Flood Control Measures", flood control intake structures would only be needed above Mile 10.0 to the county line for both the locally preferred and NED plans. All intake structures were located and sized to keep 1% chance flood flows off of all buildings within the existing 1% chance (100-year) Mill Creek flood plain. For this reason, some intake structures are located on Mill Creek itself while other structures are located on tributaries to prevent tributary flooding from occurring within the existing Mill Creek flood plain. The most significant intake structure within the study area is located near the Butler County Hamilton County line at the confluence of Mill Creek and East Fork Mill Creek (drainage area equals 42 square miles). With a total inflow of about 6500 cfs, nearly 5200 cfs are needed to be diverted into the tunnel at this location to obtain the desired level of protection. One limitation placed on this design was the request from Metropolitan Sewer District (MSD) to not allow runoff into all intake structures leading into the tunnel for events more frequent than a 50% chance (2-year) flood. MSD desired to use the more frequent events for storage of combined sewer overflows as discussed in the following section. With this restriction and using a relationship of channel flow to weir flow at the confluence of these two streams, a weir length of nearly 2300 feet is needed to be able to divert 5200 cfs to the intake structure. As the remaining 1300 cfs channel flow is combined with the downstream local flows, additional flood control intake structures are needed to prevent structural flooding. The HEC computer program HEC-HMS "Hydrologic Modeling System" was used to determine the above ground flows as well as the flows diverted and routed through the tunnel to the barrier dam for this screening level phase. Based upon this type analysis, it was determined that approximately 9700 cfs is needed within the tunnel at the barrier dam to provide the above ground level of protection. This tunnel will operate as an inverted siphon with the outlet level near the barrier dam. For the detailed analysis phase to follow, the computer program SWMM "Storm Water Management Model" will most likely be used to add and route the tunnel flows to the barrier dam.

COMBINED SEWER OVERFLOW CONTROL

At present Metropolitan Sewer District (MSD) operates an extensive sewer network throughout Hamilton County. A significant portion of this sewerage servicing the older areas of the county are combined, collecting both storm runoff and sanitary wastewater in a single pipe. During dry weather, sewage flows are collected in a number of major interceptor sewers located parallel to Mill Creek and are transported to the Mill Creek Waste Water Treatment Plant (WWTP) for treatment. During periods of wet weather, combined runoff and sanitary flows may easily exceed the capacity of the interceptors and the WWTP. As a consequence, excessive combined sewage flows are discharged at overflow points into Mill Creek to protect downstream facilities from overloading. The implementation of a deep tunnel for flood control also offers MSD the opportunity to employ the tunnel for CSO abatement. During periods of wet weather up to a storm event occurring about once every two years, the tunnel would capture all CSO from 74 overflow locations along Mill Creek. The captured flows would then be retained in storage until such time as treatment was available at the WWTP. In order to facilitate the capture of the CSO flows from these 74 locations, new sewers would be needed, consolidating these flows and delivering them to twenty drop shaft locations that would transport the CSO into the tunnel. For less frequent storm events (therefore, those occurring less often than once every two years), the tunnel would serve a dual role capturing CSO flows and capturing excess runoff from the stream channel through five intake shafts. Once the tunnel storage volume was exceeded, mixed runoff and CSO flows would be discharged through a riser shaft just upstream of the barrier dam. Flows and settleable material remaining in the tunnel would be pumped from the tunnel following the storm event to the Mill Creek WWTP.

TUNNEL SIZING

Based upon the 9700 cfs tunnel flow at the barrier dam, it was determined that a tunnel size of 31 feet diameter is required with a grade of 0.05% to contain this flow without surcharging. This size tunnel was determined using the Darcy-Weisbach formula. The benefit to using this formula as compared to Manning's equation, for instance, is that the friction factor is based on the relative roughness obtained from the Moody diagram. With the use of Manning's equation, the selection of Manning's "n" value is a judgmental decision based upon the diameter of the tunnel.

DROP SHAFTS FOR CSO AND FLOOD CONTROL ELEMENTS

The primary function of a drop shaft structure is to carry the flow from the surface channel or sewer system to the deeper tunnel system. The primary objective of drop structure design is to minimize the effects of the falling flow by accomplishing the following:

a. Dissipate energy from the falling flow.

b. Minimize the amounts of air that are entrained from the falling flow and transported into the main tunnel.
c. Minimize the potential for odors and corrosion.

The structure should perform these tasks reliably year after year with minimal maintenance. Designers must consider the operational aspects of the tunnel and provide adequate ventilation for the main tunnel and drop structures. Vortex-generating inlets have been developed to minimize air entrainment and potential odors, and to dissipate energy from the falling flow. Plunge pools may be utilized to dissipate energy. Odor control facilities may be connected and located adjacent to the drop structure if necessary. The main types of drop structures considered for the Mill Creek project include the following:

a. Vortex Type with Tangential Inlet
b. Plunge Inlet Type (Chicago Style E-15 and D-4)

The Vortex Type with Tangential Inlet type has been used in Milwaukee since 1993 while the Plunge Inlet Type (Chicago Style E-15 and D-4) has been in use in Chicago's Tunnel and Reservoir system since the early 1980's. The Chicago E-15 type drop structure is designed for installation in rock, and has a smaller flow capacity in comparison to the D-4 type. The E-15 style deaeration chamber is shaped with an inclined roof to permit air coming out of entrainment to return up the plunge shaft. The D-4 style deaeration chamber is equipped with a separate vertical vent shaft from the top of the chamber, permitting air to exit to the ground surface, usually with an elbow at the top leading into the main plunge drop. The D-4 type, also suitable for rock conditions, was selected initially for cost estimating purposes as the D-4 has the largest relative flow capacity.

Preliminary evaluation to determine the preferred drop structure design indicates that the Chicago Type D-4 drop structure is the most suitable design for the large flows at the upper storm shaft at the confluence of Mill Creek and East Fork Mill Creek. The D-4 type design has proven experience and can pass the large design flows that are anticipated at this site. The Vortex Type with Tangential Inlet shaft design is proposed for all other storm inlets and the CSO drop shafts. Because of the significant depths, large flow differentials, and anticipated costs associated with construction of the drop structures, the number of drop structures has been minimized by consolidating flows from 74 CSO outfalls to 20 drop shafts. Additional analysis will optimize the number of drop shafts as the design progresses.

DROP STRUCTURE LOCATION

In selecting the most appropriate site for drop structure location, site selection criteria are developed so that an array of sites can be evaluated once the tunnel alignment is determined. A number of considerations are evaluated and criteria are developed based upon the following factors:

a. Proximity to the existing collection system.
b. Proximity to the proposed tunnel.

c. Land use and surface features in the vicinity (e.g. zoned for business, residential, utilities, etc).
d. Easement costs (i.e. property values).
e. Site access for construction, operation, and maintenance.

In general, the goal is to minimize overall tunnel length and thus cost. Ideally, drop structures are located in close proximity to the existing trunk sewers and the tunnel in order to minimize the lengths of connecting sewers. Land use in the vicinity of the site is evaluated to assess the impact of the drop structure on the surrounding neighborhood. Ultimately, the drop structure location is selected based on a balanced assessment of the costs of construction and the ability of the design to fit into the urban setting and meet design criteria.

VENTILLATION AND ODOR CONTROL

Air quality and odor control in the vicinity of drop structures and tunnel vent locations is a major design consideration. Odors are a primary concern of the public relative to the installation of wastewater facilities. Flow strength (concentration of wastewater and associated parameters) and turbulence caused by falling flow at drop structures is the primary factor contributing to odor problems and corrosive conditions in the vicinity of drop structures. When high concentrations of hydrogen sulfide are anticipated in a system, control of this gas in combination with application of corrosion resistant materials is necessary to increase the lifespan of system components. Lack of control may lead to early deterioration and add to costs associated with operation and maintenance. In response to this concern, the potential for odors and corrosion is evaluated based on a number of factors including wastewater characteristics, climate, and hydraulic operation of the system and proximity of venting locations to sensitive urban areas.

Vents are typically provided at drop structures rather than on the main tunnel. Construction costs are minimized and the quantity of air passing through to the main tunnel is minimized. In addition to vents at each drop structure, large vents may be provided at the upstream and downstream ends of the main tunnel. These large vent structures are often approximately equal to the diameter of the tunnel to allow for the venting of air in proportion to the volume of air in the tunnel that is displaced as the tunnel fills.

TUNNEL PUMPING STATION

For this proposed tunnel plan, there will be a new pumping station at the lower end of the tunnel to pump the stored flow into the WWTP. Conceptually, this station will have a deep bank of pumps lifting half of the height and a second bank of pumps at mid-level to lift the water into the plant, or, if necessary into Mill Creek. This pumping station will be used to dewater the tunnel into the WWTP for all filling scenarios. It will be capable of emptying the tunnel in just over two days.